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THE PHYSICAL STRUCTURE OF THREE SYMBIOTIC BINARIES

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Three Symbiotic Binary Stars

Disk accretion powers many astronomical objects, including pre-main sequence stars, interacting binary systems, and active galactic nuclei. Unfortunately, models developed to explain the behavior of disks and their surroundings – boundary layers, jets, and winds – lack much predictive power, because the physical mechanism driving disk evolution – the viscosity – is not understood. Observations of many types of accreting systems are needed to constrain the basic physics of disks and provide input for improved models.

Symbiotic stars are an attractive laboratory for studying physical phenomena associated with disk accretion. These long period binaries ($P_{orb} \sim$ 2-3 yr) contain an evolved red giant star, a hot companion, and an ionized nebula. The secondary star usually is a white dwarf accreting material from the wind of its red giant companion. A good example of this type of symbiotic is BF Cygni: our analysis shows that disk accretion powers the nuclear burning shell of the hot white dwarf and also manages to eject material perpendicular to the orbital plane (Mikołajewska, Kenyon, and Mikołajewski 1989). The hot components in other symbiotic binaries appear powered by tidal overflow from a very evolved red giant companion. We recently completed a study of CI Cygni and demonstrated that the accreting secondary is a solar-type main sequence star, rather than a white dwarf (Kenyon *et al.* 1991).

This project continued our study of symbiotic binary systems. Our general plan was to combine archival ultraviolet and optical spectrophotometry with high quality optical radial velocity observations to determine the variation of line and continuum sources as functions of orbital phase. We were very successful in generating orbital solutions and phasing UV+optical spectra for three systems: V443 Her, AG Peg, and AX Per. Summaries of our main results for these three systems appear below.

A second goal of our project was to consider general models for the outbursts of symbiotic stars, with an emphasis on understanding the differences between disk-driven and nuclear-powered eruptions. This portion of the project was also successful, as summarized below.

I. Physical Properties of Several Symbiotic Stars

A. AX Persei

In *On the Nature of the Symbiotic Binary AX Persei*, Kenyon and Mikołajewska presented optical/ultraviolet photometric and spectroscopic observations for the symbiotic binary AX Persei. This system contains a red giant that fills its tidal lobe and transfers material into an accretion disk surrounding a low mass main sequence star. The stellar masses – $M_g \sim 1\,M_\odot$ for the red giant and $M_h \sim 0.4\,M_\odot$ for the companion – suggest AX Per is poised to enter a common envelope phase of evolution.

The disk luminosity increases from $L_{disk} \sim 100\,L_\odot$ in quiescence to $L_{disk} \sim 5700\,L_\odot$ in outburst for a distance of d = 2.5 kpc. Except for visual maximum, high ionization permitted emission lines – such as He II – imply an EUV luminosity comparable to the disk luminosity. High energy photons emitted by a hot boundary layer between the disk and central star ionize a surrounding nebula to produce this permitted line emission. High ionization forbidden lines – such as [Fe VII] – form in an extended, shock-excited region well out of the binary's orbital plane and may be associated with mass loss from the disk.

B. V443 Herculis

In *Spectroscopic Observations of V443 Herculis: A Symbiotic Binary with a Low Mass White Dwarf*, Kenyon, Dobrzcyka, and Mikołajewska completed an analysis of optical/ultraviolet photometric and spectroscopic observations for the symbiotic binary V443 Herculis. This system is a relatively short period system – P $\sim$ 600 days – that contains a red giant and a hot compact star similar to the central star of a planetary nebula. The red giant appears fairly normal: it does not fill its tidal lobe and has a modest amount of circumstellar dust emission. The hot component is more extreme: it appears to lie on the cooling curve of a 0.55 $M_\odot$ white dwarf with a temperature of $\sim 10^5$ K and a luminosity of $\sim 600\,L_\odot$. The lifetime of the source at this position in the HR diagram is very short – less than 10^3 yr – so we conclude that the hot component must be powered by accretion from the low velocity, red giant wind.

C. AG Pegasi

In *The Evolution of the Symbiotic Binary System AG Pegasi: The Slowest Classical Nova Eruption Ever Recorded*, we presented an analysis of new and existing photometric and spectroscopic observations of the ongoing eruption in the symbiotic star AG Pegasi. These observations showed that this binary has evolved considerably since the turn of the century. In particular, recent dramatic changes in both the UV continuum and the wind from the hot component allowed a more detailed analysis than in previous papers.

AG Peg is composed of a normal M3 giant ($M_g \sim 2.5\,M_\odot$) and a hot, compact star ($M_h \sim 0.6\,M_\odot$) embedded in a dense, ionized nebula. The hot component powers the activity observed in this system, including a dense wind ($v_r \sim 1000$ km s^{-1}; $\dot{M} \sim 10^{-6}\,M_\odot\,yr^{-1}$) and a photoionized region within the outer atmosphere of the red giant. The hot component contracted in radius at roughly constant luminosity from c. 1850 to c. 1985. Its bolometric luminosity declined by a factor of ~ 4 during the past five years, and it may now be evolving along the constant radius portion of the white dwarf cooling curve. Both the mass loss rate from the hot component and the emission activity decreased in step with the hot component's total luminosity, while photospheric radiation from the red giant companion remained essentially constant.

II. The Eruptions of Symbiotic Binary Stars

In *On the Nova-like Eruptions of Symbiotic Binaries*, Kenyon and Mikołajewska discussed three popular explanations for the nova-like eruptions observed in symbiotic binary stars and compared model predictions with recent observations. Most outbursts occur when unstable hydrogen shell burning causes a hot white dwarf to expand to a radius of 1-100 $R_\odot$. This model predicts a long duration constant luminosity phase following visual maximum, and observations of the symbiotic novae and several steady burning sources confirms this feature of thermonuclear runaway calculations. At least two symbiotics erupt when the accretion rate from a circumstellar disk onto a solar-type central star increases by 1-2 orders of magnitude. Simple accretion models emit $\sim$ 50% of the gravitational energy in the disk and the remainder in a hot boundary layer between the disk and central star. Observations of CI Cyg and AX Per support this picture for accretion rates below $\sim 10^{-4}\,M_\odot\,yr^{-1}$, but boundary layer emission vanishes for higher accretion rates. Finally, we associated observations of extra reddening and the appearance of high ionization emission lines in R Aqr with an increase in the Mira mass loss rate initiated, perhaps, by a helium shell flash above the Mira's degenerate core.

In *The Secondary Outburst Maximum of T Coronae Borealis: Implications for Accretion Disk Physics*, John Cannizzo and Kenyon examined Webbink's hypothesis that the accretion of a torus of matter onto a main sequence star caused secondary maxima during the 1866 and 1946 eruptions of the recurrent nova T CrB. Our simple 1-D hydrodynamical calculations showed that the accretion disk viscosity must increase with time to produce light curves resembling observations. We adopted a model in which the viscosity parameter α increases from a seed value α_i to a final value α_f via the relation $\alpha(t) = \alpha_f/[1 + (\alpha_f/\alpha_i)\exp(-t/\tau)]$. The observed light curve requires $\alpha_i = 10^{-3}$ and $\alpha_f = 3$ if the initial torus mass is $10^{-4}M_\odot$ and the viscous growth time, τ, is the orbital time at the initial radius of the torus. Our model implied that the physical mechanism responsible for producing the viscous dissipation in the accretion disk has a fast growth rate and saturates to an α of order unity. Balbus & Hawley identify an MHD instability with the same growth rate and saturation viscosity required by our phenomenological model. The good agreement between parameters estimated from observations and those derived from a physical viscosity mechanism suggested that this instability is a promising source for the accretion disk viscosity.

In *On Symbiotic Stars and Type Ia Supernovae*, Kenyon and collaborators examined the possibility that wide binaries containing a red giant and a white dwarf produce a significant fraction of type Ia supernovae (SN Ia). These binaries probably cannot account for SN Ia events if the white dwarf mass must evolve to the Chandrasekhar limit during the expected lifetime of the red giant primary star. However, symbiotic binaries are good candidates for helium detonation supernovae in low mass white dwarfs. If helium detonations can produce the majority of SN Ia events, then symbiotic stars might account for a large fraction of type Ia supernovae.

In *The Secondary Outburst Maximum of T Coronae Borealis: Hydrodynamic Simulations of the Blob and Accretion Disk,* J. Cannizzo, M. Ruffert, and Kenyon completed an SPH calculation of an accretion disk around a main sequence star. The goal is to try to understand the evolution of the outburst of T CrB, a symbiotic with a lobe-filling red giant primary. We found that a blob ejected by the giant gets smeared out into a disk within several dynamical time scales. Once a disk is formed, it evolves as a normal viscous disk. We were able to account for the secondary maximum in T CrB if the viscosity within the disk grows from $\alpha \sim 10^{-5}$ to $\alpha \sim 3$ with a local growth rate of $2/\Omega$, where Ω is the orbital frequency.

In *He I Emission Lines in Symbiotic Stars,* D. Proga, J. Mikołajewska, and Kenyon analyzed the He I spectrum of symbiotic binaries. As in earlier studies, we found significant deviations from case B predictions for every system considered. In most cases, the $\lambda\lambda 5876$, 6678 lines serve to distinguish between *S–type* and *D–type* symbiotics in that $I(\lambda 6678)/I(\lambda 5876) \gtrsim 0.50$ for *S–types* and $I(\lambda 6678)/I(\lambda 5876) \sim 0.25$ for *D–types.* We followed Almog & Netzer (1989) and derive predicted intensity ratios for comparison with the observations. Our models indicate densities of $n_e \sim 10^{10}$ cm^{-3} for most *S–type* systems and $n_e \lesssim 10^{10}$ cm^{-3} for all *D–type* systems. The He I intensity ratios require large optical depths, $\tau_{3889} \sim 100$–1000, for most sources; the nebular sizes are then roughly 1 AU for *S–types* and 10 AU for *D–types.* These results agree with previous density and size estimates for symbiotics; thus, our He I model provides a useful diagnostic for the physical conditions within dense photoionized nebulae.

Publications

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